Heat Transfer Enhancement in Vertical Channel for Two Phase Flow by using Compound Turbulater

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Abstract

The mixture of air-water (gas-water) flow has many applications in chemical and mechanical industries and heating systems (heat exchangers and manifolds), fields of energy, petroleum, refrigeration, and air conditioning. The characteristics of the mixture (water, air) have been investigated experimentally in a rectangular channel placed vertically by using internal heated plate (compound turbulater ribs and groove) with different volume flow rates of water and air, and constant heat flux. The dimensions of the rectangular channel are (5 × 3 × 70 cm). The aim of these experiments is to display the two-phase flow phenomenon with heated plate (three compound turbulater) for different water and air discharges. Four different values of water flow rate (3, 6, 9, and 12 l/min), three different values of air flow rate (8.33, 16.67, and 25 l/m)، and three different values of heat power (109.65, 150, and 235 watts) have been used. The temperature of the mixture has been measured at several locations along the channel, and the behavior for the mixture inside the channel has been visualized by using video camera. The results showed that when water and air flow rate increases, flow becomes turbulent, vortices develops around the heated plate, the exit temperature decreases and local heat transfer coefficient increases. The compound turbulater with relative groove position (g/p)=0.55 had a higher rate of heat transfer ،where the percentage difference from other model (g/p = 0.73 and 0.37) were 4% and 6% , respectively due to the fact that the flow mixing and sweeping surface in these types of compound turbulater are more than others type.

Key words: Heat transfer, vertical channel, two phase flow, turbulaters, compound turbulater

الخلاصه

الخليط من تدفق الماء والهواء (غاز – ماء) له العديد من التطبيقات في الصناعات الميكانيكية والكيمياوية و انظمة التسخين (المبادلات الحراريه والفتحات)،مجال الطاقة ،النفط،التبريد والتكيف.خصائص هذا الخليط (ماء – هواء) تم التحقق منه عمليا داخل قناة مستطيلة وضعت عموديا بواسطة استخدام لوحة مسخنة (معرقل مركب من الاضلاع وتجويف) مع معدلات تدفق حجمية مختلفة من الماء والهواء وبثبوت الحرارة على وحدة المساحة .ابعاد القناة المستطيلة (5×3×70 سم) .الهدف من هذه التجارب هو لبيان ظاهرة الجريان ثنائي الطور بوجود لوحة المسخنة (المعرقل المركب بثلاث اشكال) ولمختلف معدلات التدفق من الماء والهواء .اربع قيم مختلفة لتدفق الماء (3,6,9،و12)لتر/دقيقة،ثلاث قيم مختلفة لتدفق الهواء (8.33,16.67،و 25)لتر / دقيقة،و ثلاث قيم مختلفة من الطاقة الحرارية (109.65,150،و 235 واط) تم استخدامها.درجة حرارة الخليط تم قياسها في مواقع متعددة على طول القناة،و وتم تصور سلوك الخليط داخل القناة باستخدام كاميرا الفيديو.اظهرت النتائج بانه عند زيادة تدفق الماء والهواء الجريان يصبح مضطربا،وتتكون الدوامات حول اللوحة المسخنه ،درجة حرارة الخروج تقل ومعامل انتقال الحرارة سوف يزداد. المعرقل المركب مع موقع نسبي للتجويف = 0.55 له معدل اكبر في انتقال الحرارة ، حيث ان النسبة المئوية للفرق عن الانواع الاخرى (g/p = 0.73 و 0.37) كانت 4% و 6% بالتعاقب ويرجع ذلك إلى حقيقة أن الخلط والسطح الكاسح في هذه الأنواع من مثيرات الاضطراب المركبة هي أكثر من الانواع الاخرى.

الكلمات المفتاحية:– انتقال الحرارة، قناة عمودية، جريان ثنائي الطور، مثيرات اضطراب، مثيرات اضطراب مركبه.

1. Introduction

Two-phase flow is a complicated system that is collected of two mixed phases (such as liquid and gas, gas and solid, and liquid -liquid) flowing together. The mixture of air-water (gas-water) flow has many applications in chemical and mechanical industries and in a nuclear – power generation, fields of energy, petroleum, refrigeration, and air conditioning. A recognized method to increase the heat transfer from a surface is to roughen the surface either by employ of regular geometric roughness elements on the surface or randomly with a sand grain. Also the increase in heat transfer is accompanied by an increase in the resistance to fluid flow. The two-phase (gas–liquid) flow was investigated in theoretical and experimental studies. (Vlasogiannis *et.al.*,2002) experimentally defined the influence of flow regime on heat transfer coefficient in the vertical channels and reported visual observations by a high-speed video camera to construction a flow regime map. (Hetsroni *et.al.*,2003) experimentally studied the flow regimes and heat transfer for two phases (air-water) flow in 8° inclined tubes.Studied the hydrodynamic pattern in the pipes by analyzing high-speed video images and conductive tomography. By infrared thermography the thermal patterns on the heated wall and local heat transfer coefficients were obtained.(Asano *et.al*.,2004) experimentally clarified the two-phase flow characteristics in a plate heat exchanger with a single channel placed in a vertical plane by visualizing it by a neutron radiography method and measured the two-dimensional void fraction distributions.(Kim and Sin ,2006) experimentally investigated the effects of tube outlet direction, tube protrusion depth as well as mass flux, and quality of the air and water flow distribution in a horizontal round header – flat tube geometry simulating a parallel flow heat exchange and they specified the flow at entrance of header as annular. (Wang and Sunde´n ,2007) experimentally investigated the heat transfer and friction characteristics in a square duct roughened by various-shaped ribs on one wall. (Mahood et.al.,2009) performed an analytical solution to show how the pressure being dropped in pipe placed horizontal for two - phase flow (water-air) where it is affected by the size and shape of the obstruction.(Ansari and Arzandi ,2012) explained the effects of using ribs of different heights on regime boundaries in rectangular ducts that are smooth and ribbed for the two phase flow (air-water) and presented the flow map diagrams. (Habeeb and Al-Turaihi ,2013) experimentally and numerically studied the two-phase flow phenomena around multi- shape obstacles (circular, square-section and triangular-section) in a rectangular enlarging channel for the two phases with different air and water flow rates to visualize the two phase flow phenomena as well as to study the effect of pressure difference through the channel with the existence of the obstacle.(Al-Turaihi and Fadhil,2016) experimentally and numerically investigated the characteristics of the two phase flow in a rectangular channel Placed vertically by using internal rib with different volume flow rates of water and air , and constant heat power, and shows the effect of varying the discharge of water and air on the heat transfer coefficient.

In this paper, the experimental study of the two phase flow (water-air) in a vertical rectangular channel with compound turbulater has been investigated.

2. The Experimental Equipment and Procedure:

Experimental rig was constructed to study the enhanced of heat transfer for working fluid inside a rectangular channel by compound turbulater with two phase flow, the equipment used for the experimental test and the measuring system is shown in figure (1) which consists of:

1. A pump connected with flow meter. The water pump (marquees) is used to pump water into the channel. It had a maximum discharge of (30 L/min), voltage in (220 volts), and a maximum head of (30m). The flow meter had a flow rate ranged from (1.8-18 L/min).
2. An ROSY Z-0.036/8 Air Compressor was used to supply air (gas phase) with working pressure 0.8 Mpa , voltage 220 V ,power 1HP ,and frequency 50 Hz
3. An air flow meter used to measure the air inflow average that entered the channel with a range of (5.833-58.33 L/min).
4. A test section being used as shown in figure (1) and (2) with a rectangular cross section (5×3 cm) and a length of (70 cm) to offer the conduct of the two phase flow (gas, liquid) over the heated plate (ribs and groove).
5. A power supply has a maximum voltage (220 V).
6. Two heater with capacity (400 Watt) and voltage of 220 V.

7. Thermometer to record the temperature reading at different positions of the test channel with five thermocouples (K-type) one on the surface rib and others distributed on the test channel.
8. A Sony digital video camera recorder of DSC-W220 model used to show the behavior of the two phase flow through the channel.
9. A different operation conditions were investigated to display the influence of these conditions on temperature profile in the rectangular channel with compound turbulater, such as air flow rate, water flow rate and different values of constant heat. The chosen boundary condition is displayed in table (1).

Table 1: Values of Operation Conditions used in Experimental Work

Heat power q (watt)	Water discharge Qw (L/min)	Air discharge Qa (L/min)
109.65	3	8.33
150	6	16.67
235	9	25
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Figure (1): The two phase flow experimental rig.

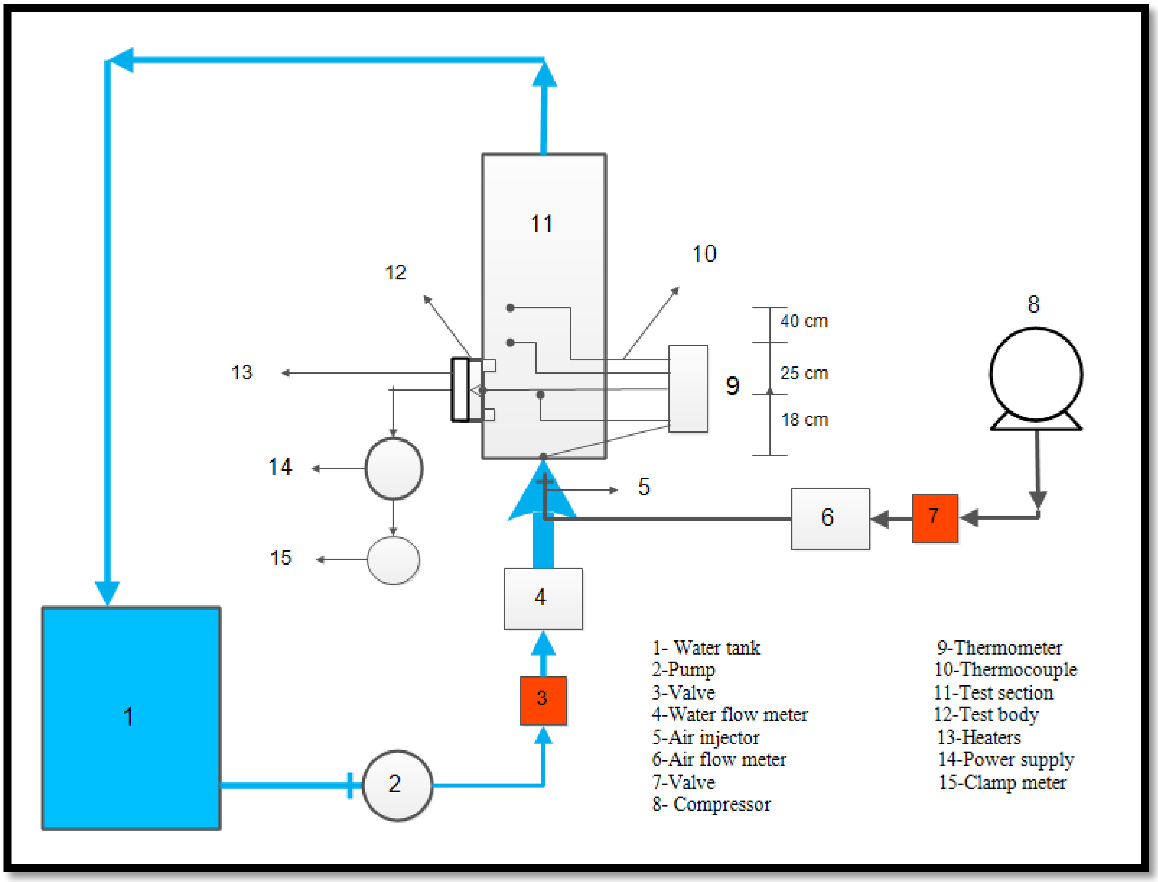

Figure (2): Schematic Diagram of the Two Phase Flow.

The experimental procedures are:

In the experimental part taking different values of flow rate, four values of water, three values of air, and three values of electric power as shown in Table (1). For the first test in this work, the following procedure was done:

1. Installing the heat plate (first model) inside the rectangular channel.
2. Turn on the water centrifugal pump at the initial value of (Turn on the water centrifugal pump at the initial value of (3 l/min).
3. Supply the electrical power to the heaters at the first value of (109.65 Watt)
4. Wait for few minutes (5-10 min) until the heated plate reach to the desired temperature
5. Turn on air compressor at the initial value of (8.333 l/min).
6. Recording the temperature by sensors which are located at five points, four of them along the test channel and one for the heated plate as well as, with recording video to observe the flow behavior.
7. Change the second value of air volume flow rate with still water constant and repeat the above steps until to finish all the air volume flow rate values.
8. Repeat all above steps with a new water volume flow rate value until to finish the entire water volume flow rate
9. The above steps were repeated for the three different values of heat flux which are shown in table (1).
10. All the above steps were repeated for the remaining two models.

3. Results and Discussion:

The effect of the varying water superficial velocity of (0.0987 m/s - 0.395 m/s), air superficial velocity of (1.4609 m/s – 4.384 m/s) ,heat power from (109.65 w -235 w),and and the effect of the relative groove position on the local heat transfer coefficient were investigated.

3.1 Effect of water superficial velocity

Figures (3) to (5) show the effect of increasing water superficial velocity on the local heat transfer coefficient results with different position for the groove in compound turbulater for various values of heat flux and air superficial velocity.

When the water superficial velocity increase, heat transfer coefficient increase due to decrease the temperature difference and increase the amount of water that follow above the heat plate inside the channel. Also adding of heated plate (ribs and groove) increases surface area of heat transfer, interrupts the development of the boundary layer of flow ,create strong turbulence intensity inside the channel leading to rapid mixing between the core and wall flow.

It can be noted that, the temperature difference decrease as the water superficial velocity increased according to the relation:

$$q = m^{\bullet} cp \, \Delta T \qquad \dots (1)$$

Where

$$m^{\bullet} = \rho \upsilon A \qquad \dots (2)$$

$$q = h \, \Delta T \qquad \dots (3)$$

Where q is the heat flux (W), $\dot{m}$ Mass flow rate, c_p the specific heat of fluid ,ρ the density of fluid, υ the superficial velocity of fluid , A cross section area , h heat transfer coefficient , and ΔT temperature difference.

From Eq. (1), it can be observed that, the temperature difference inversely proportional with the water superficial velocity.

The heat transfer coefficient increased as the water superficial velocity increased and temperature difference decreased according to Eq. (1) and Eq. (3).These equation showed that the heat transfer coefficient directly proportional to the water superficial velocity and inversely proportional to the temperature difference.

Figures (3), (4), and (5) shows the local heat transfer coefficient results for the channel fitted with relative groove position (g/p) =0.55, 0.73, and 0.37, respectively for different values of water superficial velocity. As the water superficial velocity increased from (0.0987 m/s to 0.395 m/s) at constant air superficial velocity and heat flux (1.4609 m/s and 109.65 W), respectively, the value of the local heat transfer coefficient increase from (828.52 $W/m^2.K$ to 884.5 $W/m^2.K$) for relative groove position (g/p) =0.55, also increase from (812.966$W/m^2.K$ to 858.48$W/m^2.K$) for (g/p) =0.73, and increase from (798.45$W/m^2.K$ to 848.15$W/m^2.K$) for relative groove position (g/p)=0.37.

3.2 Effect of air superficial velocity

In figures from (6) to (8) the effect of air superficial velocity on the heat transfer coefficient with the three models of the heated plate for varying values of water superficial velocity and heat were shown.

When air superficial velocity increase, the local heat transfer coefficient have been increased due to decrease in temperature difference and increase the amount of air inside the channel. Also adding of heated plate (ribs and groove) increases surface area of heat transfer, interrupts the development of boundary layer of flow ,create strong turbulence intensity inside the channel leading to rapid mixing between the core and wall flow. The increase in the local heat transfer coefficient was according to Eq. (1) and (3), respectively, where the temperature difference inversely proportional to the air superficial velocity.

From Eq. (1) and Eq. (3), it can be found that, the heat transfer coefficient have been increased as the air superficial velocity increased and temperature difference decreased due to the directly proportional with the air superficial velocity and inversely proportional with the temperature difference. Also when air flow rate increases , the flow becomes unstable and unsymmetrical over the heated plate with an increase in the size and number of bubbles .This is due to the high velocity of water and air which leads to more disturbance in the flow, which is taken for the test section by using digital video camera.

Figures (6), (7), and (8) shows the local heat transfer coefficient results for the channel fitted with heated plate having relative groove position (g/p)=0.55, 0.73, and 0.37 for varying values of air superficial velocity. As the air superficial velocity increased from (1.4609 m/s to 4.384 m/s) at constant water superficial velocity and heat (0.0987 m/s and 109.65 W), respectively, the value of the experimental heat transfer coefficient have been increased from (828.52 $W/m^2.K$ to 866.22 $W/m^2.K$) for (g/p)=0.55, from (812.966$W/m^2.K$ to 867.21$W/m^2.K$) for (g/p)=0.73 ,and from (798.45$W/m^2.K$ to 848.67$W/m^2.K$) for 0.37.The effect of air superficial velocity on the heat transfer coefficient results was the same effect of water superficial velocity on it, but with less percentage because water is the primary phase and have a thermal conductivity higher than the thermal conductivity of air.

3.3 Effect of groove position

Figure (9) shows the local heat transfer coefficient results for three shapes of compound turbulater with respect to the air superficial velocity at (0.0987 ,0.395 m/s) water superficial velocity and (109.65 W) of heat , the air superficial velocity increased from (1.4609 m/s) to (4.384 m/s) leading the experimental local heat transfer coefficient results to increase from (838.53 $W/m^2.K$ to 914.1 $W/m^2.K$) for compound turbulater with relative groove position (g/p)=0.55, from (834.41 $W/m^2.K$ to 882.08 $W/m^2.K$) for compound turbulater with (g/p) =0.73, and increase from (821.58 $W/m^2.K$ to 865.59 $W/m^2.K$) for compound turbulater with (g/p)=0.37. Attributing the cause of this effect to the presence of the ribs and groove in the channel, where these turbulater provides additional surface area for heat transfer and creates strong turbulence intensity inside the channel by breaking the laminar-sub layer leading to rapid mixing between the core and wall flow, and as a result of this effect, the heat transfer coefficient results increase because of both increasing surface area and increasing turbulence.

Thus the compound turbulater with relative groove position (0.55) had a higher rate of heat transfer of the other models, because after the Collide the flow with the first rib and then with the central groove will consist at this position strong swirls and more turbulence flow and thus increase the surface area of the heat transfer and increases the chance of contact with the surface of the turbulater higher than the other compound turbulater.This also shown in figure (10) which gotten from the video that recorded during the experimental work at specific water and air discharge.

In addition, it can be said that more increase in the heat transfer for relative groove position 0.55 and 0.73 is due to the fact that the flow mixing and sweeping surface in these types of compound turbulater are more than those of the relative groove position 0.37.

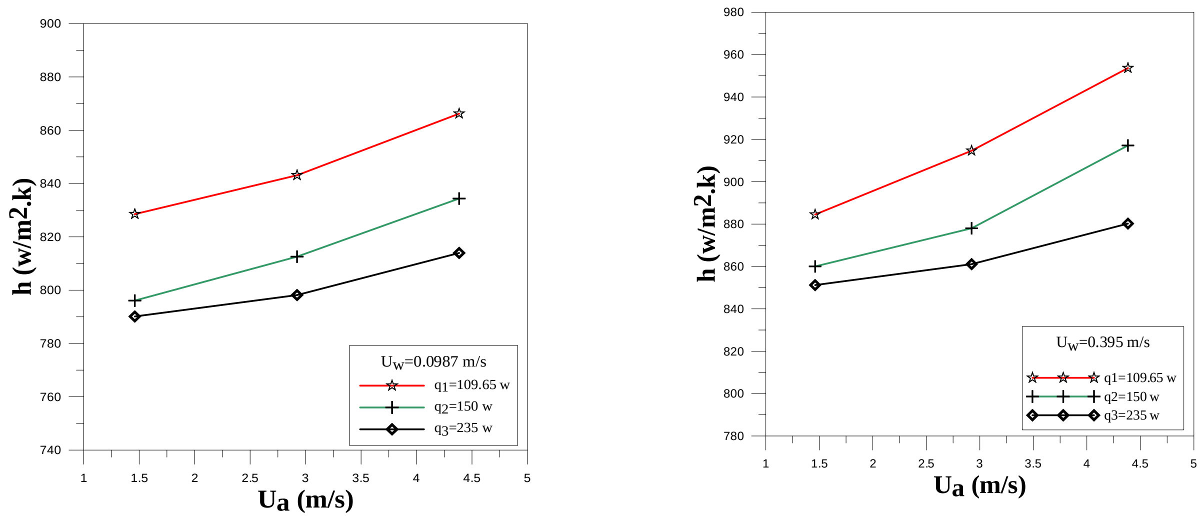

Figure (3): Effect of water superficial velocity on the heat transfer coefficient for relative groove position 0.55.for different heat flux.

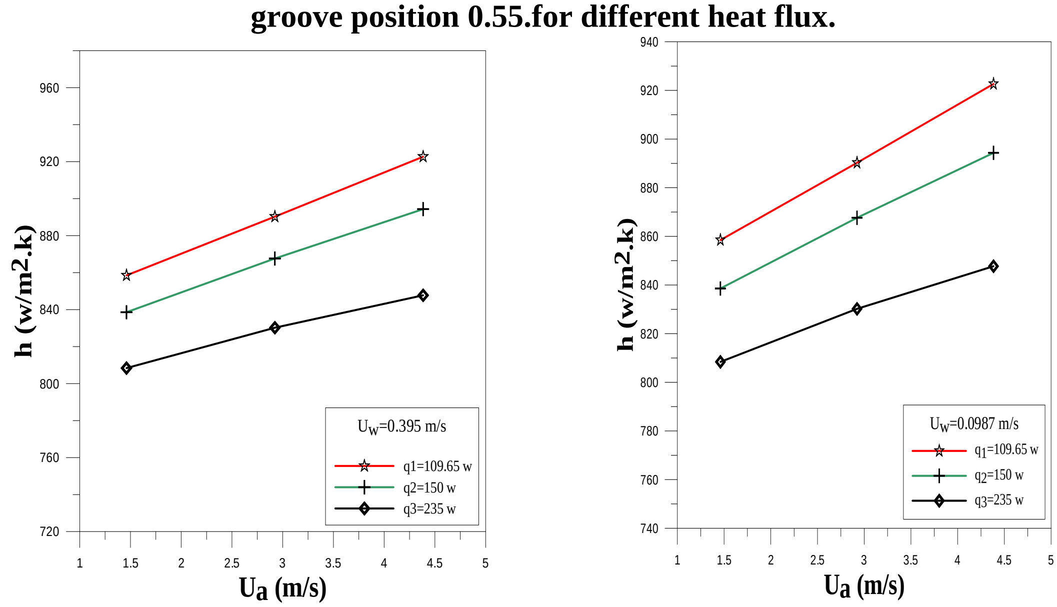

Figure (4): Effect of water superficial velocity on the heat transfer coefficient for relative groove position (g/p) = 0.73 for different heat flux

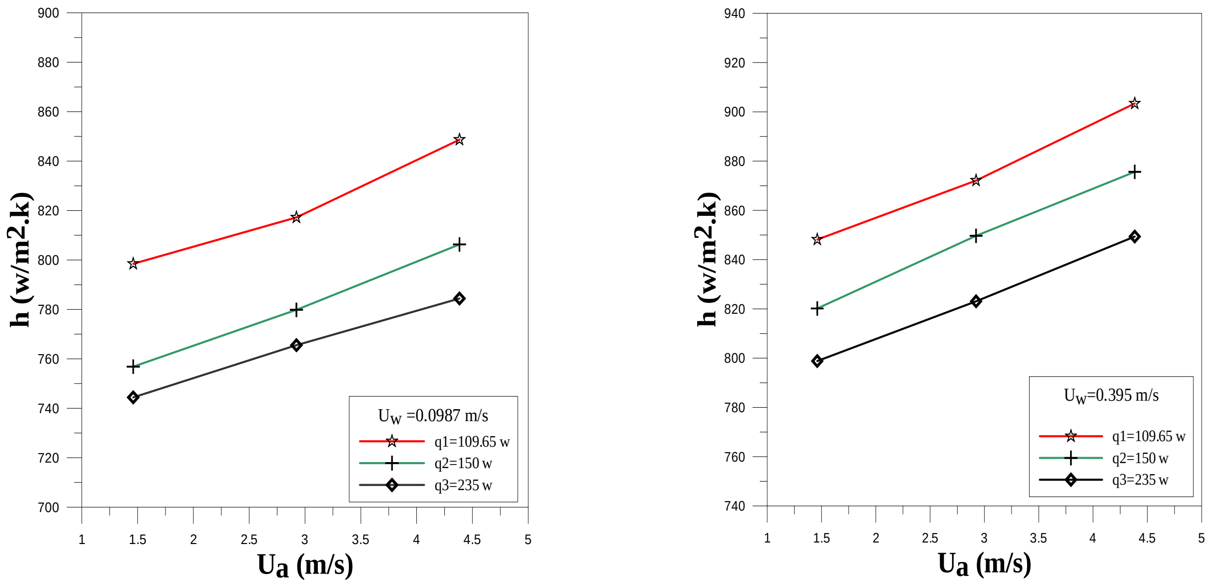

Figure (5): Effect of water superficial velocity on the heat transfer coefficient for relative groove position 0.37 for different heat flux

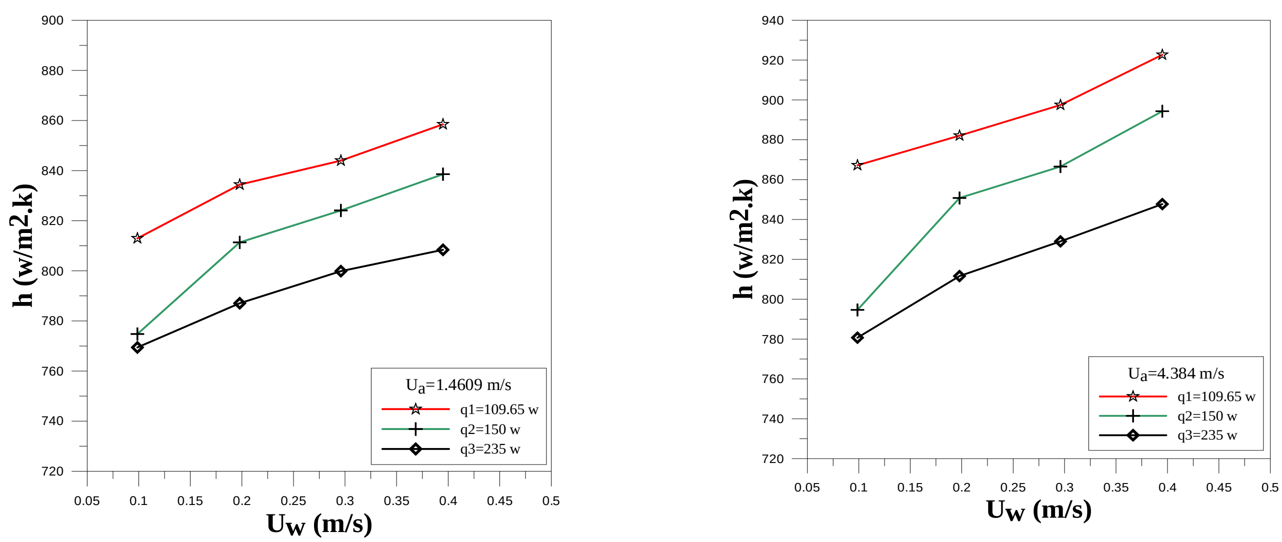

Figure (6): Effect of air superficial velocity on the heat transfer coefficient for relative groove position 0.73 for different heat flux

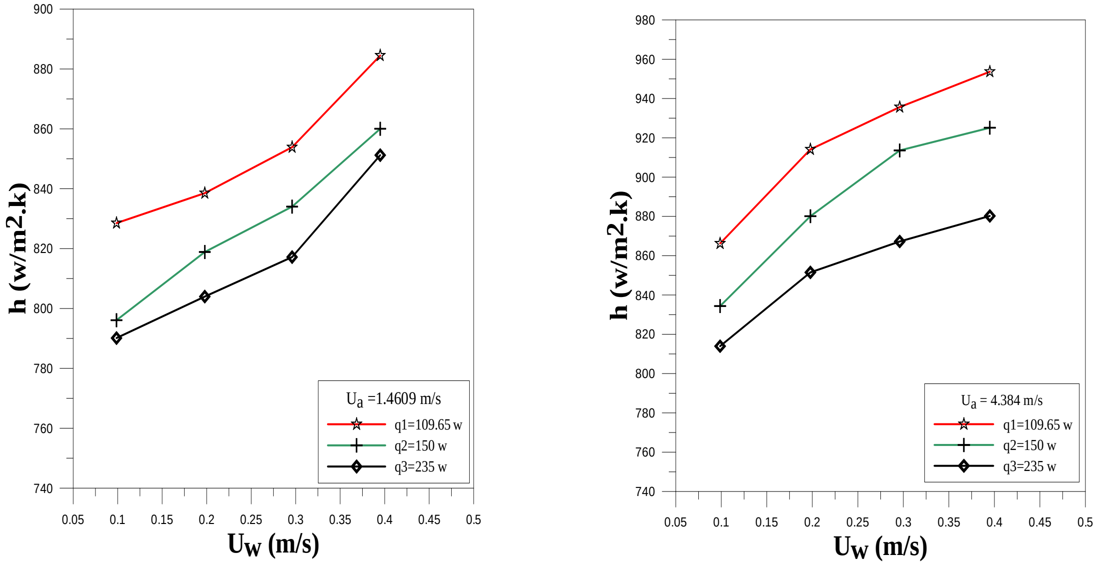

Figure (7): Effect of air superficial velocity on the heat transfer coefficient for relative groove position 0.55 for different heat flux.

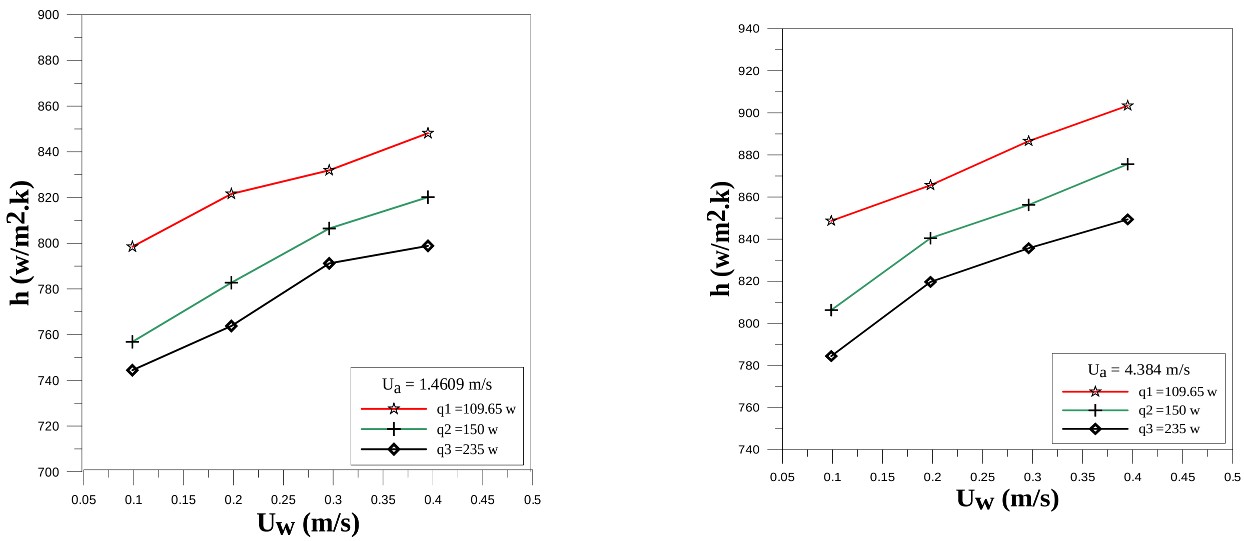

Figure (8): Effect of air superficial velocity on the heat transfer coefficient for relative groove position 0.37 for different heat flux.

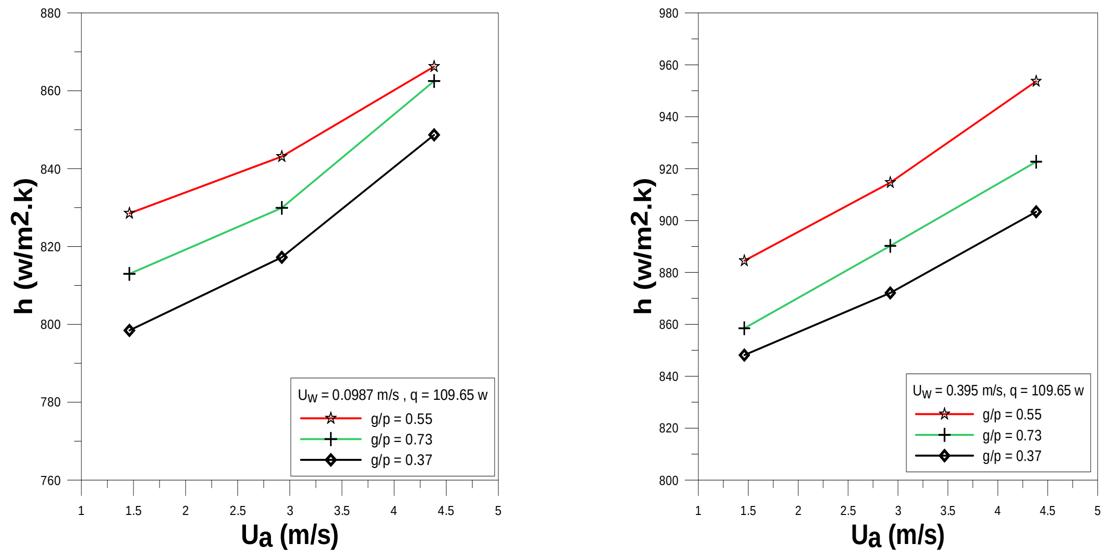

Figure (9): Effect of relative groove position on heat transfer coefficient at different water superficial velocity and constant heat flux

Figure (10) : Flow image for g/p = 0.55, 0.73, and 0.37, respectively at q = 109.65 w

4. Experimental Validations

In order to demonstrate the validity and precision of the turbulence model and experimental procedure of pervious work for (Fadhil 2017 [84]) an empirical correlation is used to calculate the heat transfer coefficient for two phase flow (water-air) around a two-dimensional heated body in a vertical rectangular channel of dimensions (10×3×70 cm). Then, the empirical heat transfer coefficient is compared with the experimental heat transfer coefficient. The empirical predicted correlation for the local heat transfer coefficient (h_x) was derived as a function of the superficial velocity of continuous and dispersed phase (water and air), heat flux, rib shape, and area of the rib which exposed to the flow.

The local heat transfer coefficient correlation has been produced as equation (4).

$$h_x = 0.05025\,(\upsilon_w)^{0.05974}\,(\upsilon_a)^{0.06428}\,(q)^{-0.82792}\,(A_r)^{-2.97717} \qquad \ldots (4)$$

Where h_x local heat transfer coefficient, v_w water superficial velocity, v_a air superficial velocity, and A_r area of the turbulater.

The correlation performance is shown in figure (11) with a deviation of about (3 %) was found between the experimental and the correlated data. Superficial velocity for water ranged from (0.0987 m/s) to (0.395 m/s), superficial velocity of air ranged from (1.4609 m/s) to (4.384 m/s), and heat power ranged from (109.65 W) to (235 W).

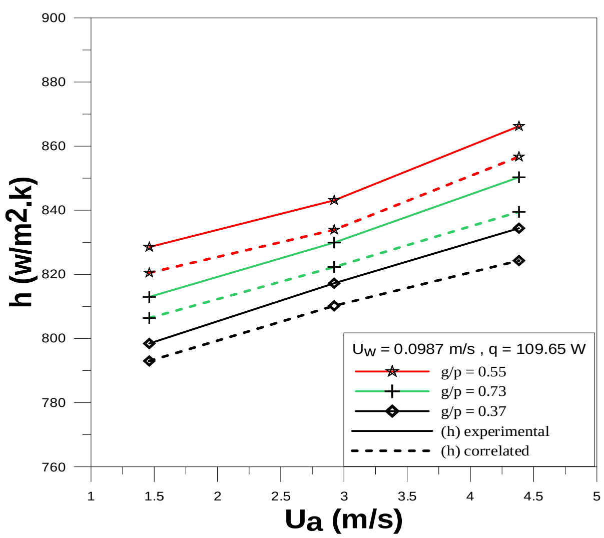

Figure (11): A Comparison between the local experimental heat transfer coefficient and the correlated values from equation (4).

5. Conclusion

In this paper, the two phase flow (water-air) has been studied experimentally. The temperature of the mixture has been measured at several positions along the test rectangular channel and the behavior of the flow has been recorded by using a video camera. It can be concluded that:

1. When the discharge of water increases, flow becomes turbulent, vortices develop around the heated plate surface, then a disperse region and strong vortex shedding are observed this led to an increase in local heat transfer coefficient with maximum percentage difference 11% for g/p = 0.55, 8.8% for g/p = 0.73, and 6.4% for g/p = 0.37. This is due to the existence of ribs and groove in the rectangular channel.
2. When air flow rates increase, the local heat transfer coefficient increase with a maximum percentage deviation of 9.5% for g/p = 0.55, 6.7% for g/p = 0.73, and 4.4% for g/p = 0.37.

3. The compound turbulater with relative groove position (0.55) had a higher rate of heat transfer of the other models due to the flow mixing and sweeping surface in these types of compound turbulater is more than another type. The experimental local heat transfer coefficient results increase, where the percentage deviation from another model (g/p = 0.73 and 0.37) were 4% and 6% , respectively.
4- A validation of the experimental work has been made with (Fadhil 2016) and it was found that the maximum difference between the two was 3%.

References

Ansari M.R., Arzandi B., 2011," Two-phase gas–liquid flow regimes for smooth and ribbed rectangular ducts" Mechanical Engineering Department, Tarbiat Modares University ,pp. 118-125 .

Doaa Fadhil Kareem , 2017,"Enhancement the Heat Transfer Coefficient for Two-Phase Flow Through a Rectangular Ribbed Vertical Channel", M.Sc .thesis, Department of Mechanical Engineering , University of Babylon,pp.84.

Hameed Balassim Mahood * Hala A. Kadim and Ali N. Salim , 2009," effect of flow-obstruction geometry on pressure drops in horizontal air-water two-phase flow " University of Missan – Missan – Iraq.

Hetsroni a G., Mewes b D., Enke b C., Gurevich a M., Mosyak a A., Rozenblit R. ,2003, "Heat transfer to two-phase flow in inclined tubes" Faculty of Mechanical Engineering, Technion—Israel Institute of Technology, pp. 173–194.

Hitoshi Asano , Nobuyuki Takenaka, Terushige Fujii ,2004, "Flow characteristics of gas–liquid two-phase flow in plate heat exchanger (Visualization and void fraction measurement by neutron radiography)", Department of Mechanical Engineering, Kobe University, pp. 223–230.

Laith Jaafer Habeeb1, Riyadh S. Al-Turaihi , 2013,"Experimental Study and CFD Simulation of Two-Phase Flow around Multi-Shape Obstacles in Enlarging Channel" Mechanical Engineering Department, University of Technology, Baghdad, Iraq, 2College of Engineering/ Department of Mech. Eng., Babylon University, Babil, Iraq ,pp. 470-486.

Lei Wang, Bengt Sunde´n , 2006, "Experimental investigation of local heat transfer in a square duct with various-shaped ribs" Lund University, pp. 43:759–766.

Nae-Hyun Kim, Tae-Ryong Sin, 2006, "Two-phase flow distribution of air–water annular flow in a parallel flow heat exchanger" Department of Mechanical Engineering, University of Incheon , pp. 1340–1353.

Riyadh S. Al-Turaihi and Doaa Fadhil kareem ,2016,"The Effect of the Two Phase Flow (Water –Air) Over Triangle Ribs on Heat Transfer Coefficient in Vertical Rectangular Duct" *Mech. Eng. Department, University of Babylon,Hilla, Iraq,* 248-262.

Vlasogiannis P., Karagiannis G., Argyropoulos P., Bontozoglou V. ,2002, "Air–water two-phase flow and heat transfer in a plate heat exchanger" ,Department of Mechanical and Industrial Engineering, University of Thessaly,pp.757 –772.